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USING THE INDUSTRIAL WASTES IN THE BASE LAYER OF PAVEMENT

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Rezumat

În cadrul acestei lucrări se urmărește posibilitatea de utilizare a agregatelor artificiale din zgură de furnal, considerate deșeu industrial, care pot înlocui, într-un anumit dozaj, agregatele naturale din compoziția unei mixturi asfaltice de tip AB 22,4. Mai mult, se prezintă posibilitatea de înlocuire a filerului uzual utilizat cu pulberi provenite din deșeuri industriale cum ar fi deșeul de la desulfurarea gazelor, generat la arderea cărbunelui energetic.

Studiile și cercetările de laborator efectuate sunt realizate conform prescripțiilor tehnice în vigoare. În acest sens, pentru evaluarea performanței diferitelor rețete de mixtură asfaltică proiectate, vor fi prezentate încercări în regim static și dinamic așa cum este prevăzut în AND 605:2016.

Rezultatele obținute în urma încercărilor de laborator efectuate au demonstrat că materialele provenite din deșeuri industriale pot fi utilizate în proiectarea de mixtură asfaltică cu scopul înlocuirii materialelor naturale, utilizate în anumite dozaje, demonstrând comportament bun la interacțiunea cu liantul bituminos uzual.

Cuvinte cheie: mixtură asfaltică ecologică, deșeuri industriale, agregate din zgură de furnal, filer din sulfat de calciu

Abstract

This paper evaluates the possibility of using artificial aggregates from blast furnace slag, considered industrial waste, which can replace, in a certain dosage, the natural aggregates in the composition of an AB 22,4 asphalt mixture. Furthermore, it is presented the possibility to replace the usual filler with powders from industrial wastes such as the desulphurization waste, generated by the combustion of the energetic coal.

Laboratory studies and researches are carried out according to prescribed techniques. For this purpose, for the evaluation of the performance of the asphalt mixture recipes will be evaluated by static and dynamic tests as described in AND 605: 2016.

The results of this study show the possibility of using asphalt mixtures with different dosages of industrial wastes in composition.

The results obtained from the laboratory tests have shown that materials from industrial waste can be used in the design of asphalt mixtures with the purpose of replacing natural materials, used in certain dosages, which demonstrates good behavior in interaction with the usual bituminous binder.

Keywords: ecological asphalt mixture, industrial waste, blast furnace slag aggregates, calcium sulphate filler.

1. INTRODUCTION

At global level (Figure 1) the orientation towards the field of recycling and recovery of industrial waste is promoted through coherent criteria regarding the technical compatibility and the integration of the materials in the environment, but in our country there are few research centers with interest in this field, focused on recycling in the metallurgical or cement concrete.

The new national and international regulations require that waste management to be according to priority hierarchy by the following steps: prevention, minimization, recovery, recycling, reuse and disposal.

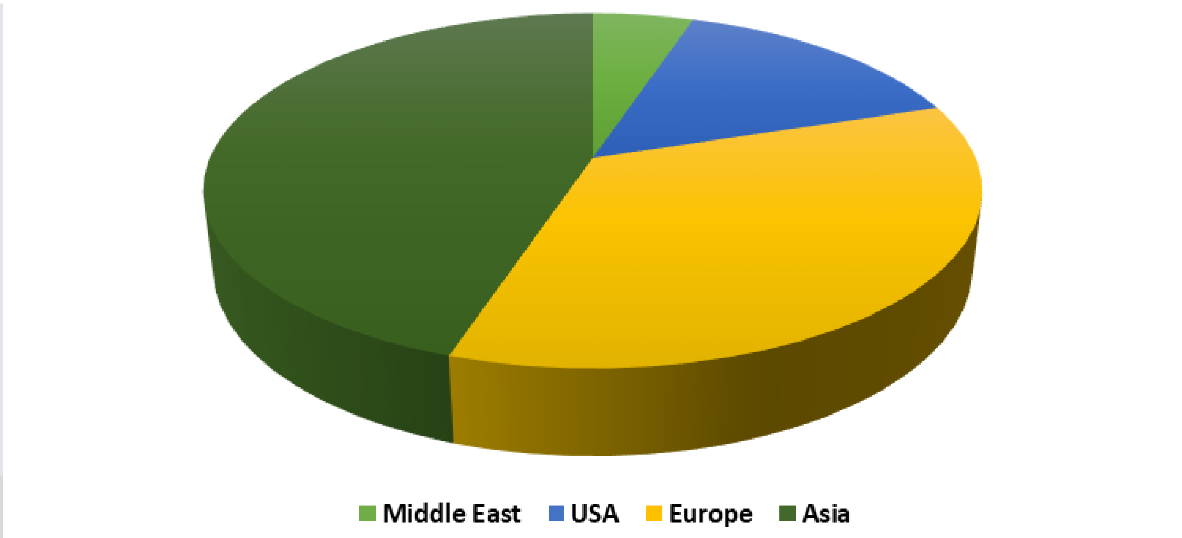

Figure 1. Recycling of industrial waste worldwide [1]

According to European legislation, by 2020, waste producers and local public administration authorities must achieve a level of readiness for reuse, recycling, and other material capitalization. The road construction sector requires measures to reduce energy consumption, negative environmental impacts and, most importantly, reduce the cost of using raw materials. It was intended to contribute to sustainable development by adhering to relevant EU policies and reducing the environmental impact associated with road construction. This has shown that there are technologies that enable asphalt mixture recycling, as well as the use of industrial waste or bio-binders, solutions that are adequately integrated into the design of innovative asphalt mixtures, thereby increasing their commercial viability. [2]

Another waste material used to improve asphalt mixture properties is crumb rubber: various types of rubber asphalts are used in some mixes, part of the coarse aggregate is replaced with rubber while, in others, it is the binder that is modified. The performance of an asphalt rubber mixture depends on the physical and chemical properties of the materials used and the interaction of these materials. Some anticipated benefits of adding crumb rubber to the asphalt concrete pavement, in a pavement engineer's view, are increased flexibility, skid resistance, fatigue life, as well as reduced crack reflection control, traffic noise, and aging. [3]

Prithvi S. Kandhal has evaluated in the laboratory and in field several types of industrial waste that can be used in asphalt mixtures and specified that their recycling in road construction should be encouraged. However, it is necessary to address technical, environmental and economic concerns before using at large-scale new materials. The first step in this direction is the laboratory evaluation of industrial waste materials as well as the analysis of asphalt mixtures containing such industrial wastes followed by experimental sectors on these solutions. Hot asphalt mixtures containing one or more industrial waste in different proportions should behave as well as the standard dosage of the same asphalt mixture or even be improved. [4]

In the final report of the research study entitled "Industrial waste utilization in motorway construction" developed by Imtiaz Ahmed for the United States Department of Transportation, the use of several materials from industrial waste such as used tires, waste from used glass, materials from road recycling, slag and ashes, reused building materials, steel muds and sludge was analyzed. The results of the studies are favorable to their use and support the reintroduction of certain products considered as waste and to support sustainable development. [5]

2. OBJECTIVE

The objective of this study is to determine the performance of asphalt mixtures with industrial wastes in composition by using steel slag aggregates and industrial waste filler and compare them to those achieved on the standard asphalt mixture AC22,4 T N 50/70, using only natural materials. The studies were made on several dosages of industrial waste in the composition of asphalt mixture.

The classic asphaltic mixtures dosing was made with natural aggregates of limestone, limestone filler and bitumen D 50/70. In this experimental part, the possibility of replacing 20 or 30% of the existing natural aggregates in the AB 22.4 asphalt mixture composition with artificial aggregates from industrial waste such as blast furnace slags were evaluated. In addition to this ecological benefit to the asphalt mixture and the environment, the possibility of replacing the limestone filler commonly used in asphalt mixtures with filler from industrial waste such as calcium sulfate from the thermoelectric power plants in two dosages was analyzed. [10] [13] [14]

3. MATERIALS

3.1 Aggregates

At present, about 90% of all aggregate production in Europe comes from natural extracted resources from quarries and ballasts. Exploiting them from the riverbeds and mountain massifs raise serious environmental and nature protection problems, and so lately the focus has been on replacing them.

Aggregates produced by recycling should not be regarded as competitors of the aggregates produced in quarries, but rather their use together is strategic for securing Sustainable Supply Mix (SSM). [6]

Despite the influence of the aggregate grading on the asphalt mixtures behavior the study developed in this work was based on an AB 22.4 asphalt mixture produced with two different types of aggregates (conventional and artificial) and with two different types of fillers (limestone and calcium sulfate) in various dosages. [7] [8]

Limestone aggregates and artificial aggregates are currently well known and utilized based on the success of the artificial aggregates that come from industrial waste such as steel slags. Limestone has very different physical and mechanical qualities and their use in road works is made in relation to these qualities. Due to the less dense structure and weaker mechanical resistance, the limestone is used less in heavy traffic pavement structures. The steel slag aggregates have demonstrated, in numerous situations, that the solution is to use them after processing and sorting to the right size and can successfully replace the quarry and gravel aggregates. [9] [10]

Table 1. Physical properties for natural and artificial aggregates

No.	Characteristics of aggregates according to SR EN 13043	European standard	Limestone aggregates	Steel slag aggregates
1	Wear resistance (Micro Deval)	SR EN 1097-1/2011	M_{DE} 15	M_{DE} 25
2	Coarse aggregate fragmentation resistance (Los Angeles)	SR EN 1097-2/2010	LA_{30}	LA_{25}
3	Resistance to freeze/thaw	SR EN 1367-1/2007	F_1	F_1

The results obtained in laboratory shows that steel slag aggregates have a smaller wear resistance, from this point of view the limestone aggregates can be used in a lower road technical class while steel slag aggregates can be used in superior road technical class. The coarse aggregate fragmentation resistance and also the resistance to freeze/thaw demonstrates similar behavior for the evaluated aggregates.

3.2 Fillers

Mineral powders used as fillers in the asphalt mixture process are: limestone dust (obtained by grinding compact limestone, mosaic limestone, containing more than 90% calcium carbonate), finely ground chalk powder (obtained by fine grinding of the dry chalk), the lime dust that has been slaked in powder (it is obtained by slaking the lime of the building blocks with amounts stoichiometrically calculated, water or steam, followed by appropriate separation). The filler has the quality of not reacting chemically with bituminous organic binders, ensuring a good bonding of the binder to the filler granules, and its granules must be porous as not to increase the consumption of binder by absorption. [11] [12]

It is well known that thermal power plants are universally classified as industrial waste with severe ecological impact, especially since their elimination from coal-fired power generation takes place massively on narrow geographic areas and often even point if the generation area is reported to the scale of a larger natural area. Moreover, another type of industrial waste generated by the burning of coal is calcium sulfate formed by the chemical reaction between limestone filler ($CaCO_3$) and sulfur dioxide (SO_2) gas after the desulphurization of the furnace gas. In the studies and researches carried out in this paper, it is intended to demonstrate that this type of industrial waste can be used to make asphalt mixtures as well as their physical-mechanical characteristics. [13] [14]

Table 2. Physical properties for natural and artificial filler

Test	Volumetric mass[g/cm^3]	Humidity [%]	Solubility [%]	Porosity [%]	Methylene blue [g solution / kg fraction]	Grinding finess Blaine (cm²/g)
Standard	SR EN 1097-7	SR EN 1097-5	SR EN 1744-1	SR EN 1097-4	SR EN 933-9	SR EN 196-6
100% limestone filler	2.71	0.3	1.4	26	2.39	4302
100% calcium sulfate filler	2.3	8	0	45	1.7	1495
70% calcium sulfate filler + 30% limestone filler	2.41	5.69	0.42	40	1.7	2337
50% calcium sulfate filler + 50% limestone filler	2.505	4.15	0.7	35.5	2.045	2899
20% calcium sulfate filler+ 80% limestone filler	2.62	1.84	1.12	26	2.39	3741

In an effort to investigate the effect of filler type and quantity which can be used in asphalt mixture composition, a series of laboratory tests have been performed on different dosages of calcium sulfate filler. The volumetric mass shows a lower value compared to limestone filler with approximatively 15%. From the point of view of water content, it was found that the calcium sulfate filler has a very high humidity, which according to Romanian standard is not fulfilling the condition of maximum 2%, but this problem can be solved by depositing the filler in a controlled space before it is added in asphalt mixture. Solubility of fillers presented that calcium sulfate filler is insoluble in water. The porosity of the calcium sulfate filler is very high, this characteristic involves the possibility to affect the bitumen content in asphalt mixture composition. Blaine grinding finess proves a lower grinding for calcium sulfate filler with approximatively 3% lower that limestone filler.

Table 3. Stiffening effect of filler when mixed with bitumen

Delta ring and ball test[°C]	100% limestone filler	100% calcium sulfate filler	70% calcium sulfate filler + 30% limestone filler	50% calcium sulfate filler + 50% limestone filler	20% calcium sulfate filler+ 80% limestone filler
SR EN 13179-1	14	22	14	12	10
According to SR EN 13043	ΔTBA8/16	ΔTBA17/25	ΔTBA8/16	ΔTBA8/16	ΔTBA8/16

Studying the results obtained in Table 3 and according to Romanian standard, it can be said that the delta ring and ball test for 100% calcium sulfate filler conduced to a high stiffening effect compared to the same test on the limestone filler. This property of calcium sulfate filler complies with the requirements of the Romanian standard but this behavior will also have an influence in the composition of asphalt mixture.

4. LABORATORY STUDIES AND RESEARCHES

4.1 Experimental program

In this experimental part it is showed the design of asphalt mixture which was largely a matter of selecting and proportioning constituent materials to obtain good properties. In Marshal Method, the resistance to plastic deformation of the compacted cylindrical specimen of asphaltic mixture is measured when the specimen is loaded diametrically at a deformation rate per minute. The Marshall stability is defined as the maximum load carried by the test specimen at a standard test temperature of 60˚C. The flow value was the deformation that the test specimen undergoes during loading up to the maximum load. Flow was measured in this test; an attempt was made to obtain optimum asphalt content for the type of aggregates mix used and the expected traffic intensity.

The designed recipes are for asphalt mixture used in the base layer of roads structures, mixtures having maximum grain size of 22,4 mm. The used bitumen was D 50/70, aggregates were 0/4, 4/8, 8/16 and 16/22,4 and the filler was a limestone filler for the standard recipe of asphalt mixture.

Following the possibility of replacing the natural aggregates and filler, a number of 7 different compositions of asphalt mixture AB 22.4 with industrial waste in the composition were evaluated, named as shows in the following table:

Table 4. Compositions of evaluated asphalt mixtures

No.	Asphalt mixture type	Aggregates	Filler	Bitumen
1	AB 22.4	100% limestone	100% limestone	D 50/70
2		20% steel slag + 80% limestone	100% limestone	
3		30% steel slag + 70% limestone	100% limestone	
4		20% steel slag + 80% limestone	50% limestone +50% calcium sulfate filler	
5		20% steel slag + 80% limestone	100% calcium sulfate filler	
6		30% steel slag + 70% limestone	50% limestone +50% calcium sulfate filler	
7		30% steel slag + 70% limestone	100% calcium sulfate filler	

Standard asphalt mixture used in this research was prepared using limestone aggregates and limestone filler. In this composition, 20 or 30% of all sorts of limestone aggregates was replaced with steel slag aggregates. Moreover, in these new recipes the limestone filler was replaced with a dosage of 50 or 100% of industrial waste like calcium sulfate.

4.2 Laboratory tests

The tests were carried out on Marshall samples made with 50 blows on each side. Laboratory tests started with Marshall cylinders on physical-mechanical characteristics of asphalt mixtures in static mode, as required by AND 605:2016, by determining apparent density and maximum density, Marshall characteristics, water absorption. Additionally, the dynamic characteristics of the asphalt mixtures were evaluated, such as the void volume, the permanent deformations resistance (dynamic creep), the stiffness and fatigue modulus. [12]

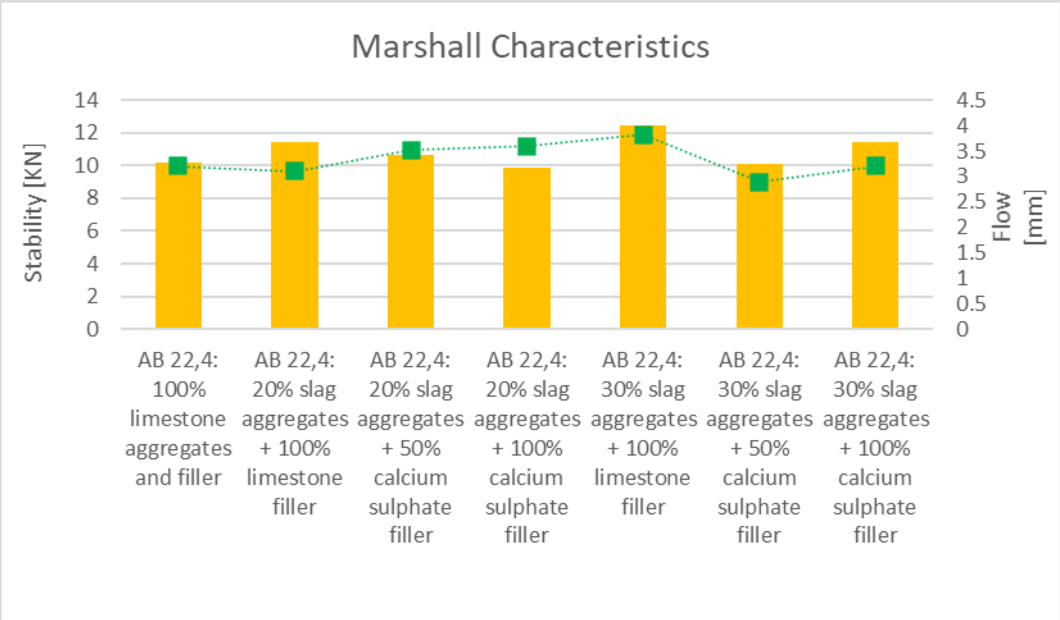

Figure 2. Marshall characteristics depending on industrial waste in asphalt mixture composition

The results in this research study lead to the conclusion that a good alternative to natural aggregate is the steel slag which leads to a good behavior of asphalt mixture; evaluating the stability demonstrates a better behavior, the utilization of 20% steel slag aggregates conduces to an improvement of structural stability by approximately 12% and the utilization of 30% increases the structural stability by approximately 22% compared with the standard asphalt mixture. At the same time, it can be seen that the flow index for the utilization of both 20 or 30% have meet increased values. Once the calcium sulphate filler is added, the results from laboratory studies demonstrate a better behavior of asphalt mixture with 20% steel slag aggregates used in composition compared to the standard asphalt mixture. The utilization of calcium sulphate filler in the composition of asphalt mixture with 30% steel slag aggregates leads to good structural stability but increased flow index.

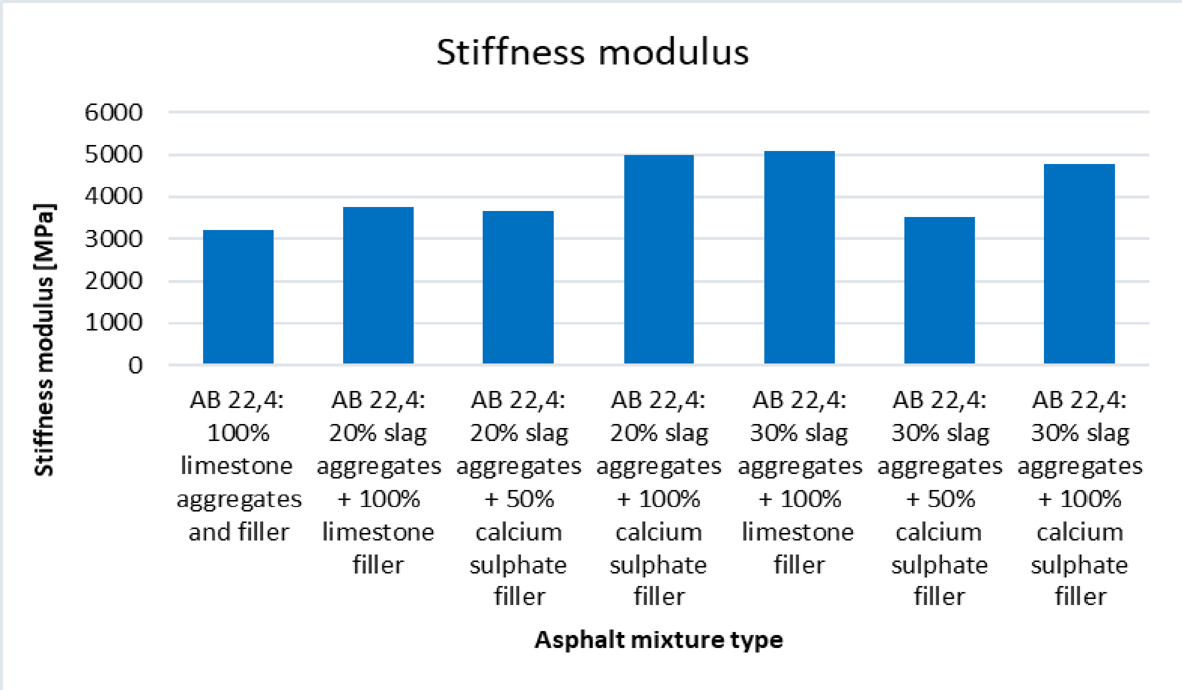

Figure 3. Stiffness modulus depending on industrial wastes in asphalt mixture composition

Stiffness modulus for all the asphalt mixture with artificial aggregates conduces to a higher performance, the same behavior is demonstrated also for utilization of calcium sulphate filler in both percentages used when compared to standard asphalt mixture. Total utilization of calcium sulphate filler leads to improved stiffness modulus by 55% in asphalt mixture with 20% steel slag aggregates and by 50% in asphalt mixture with 30% slag aggregates compared to standard asphalt mixture.

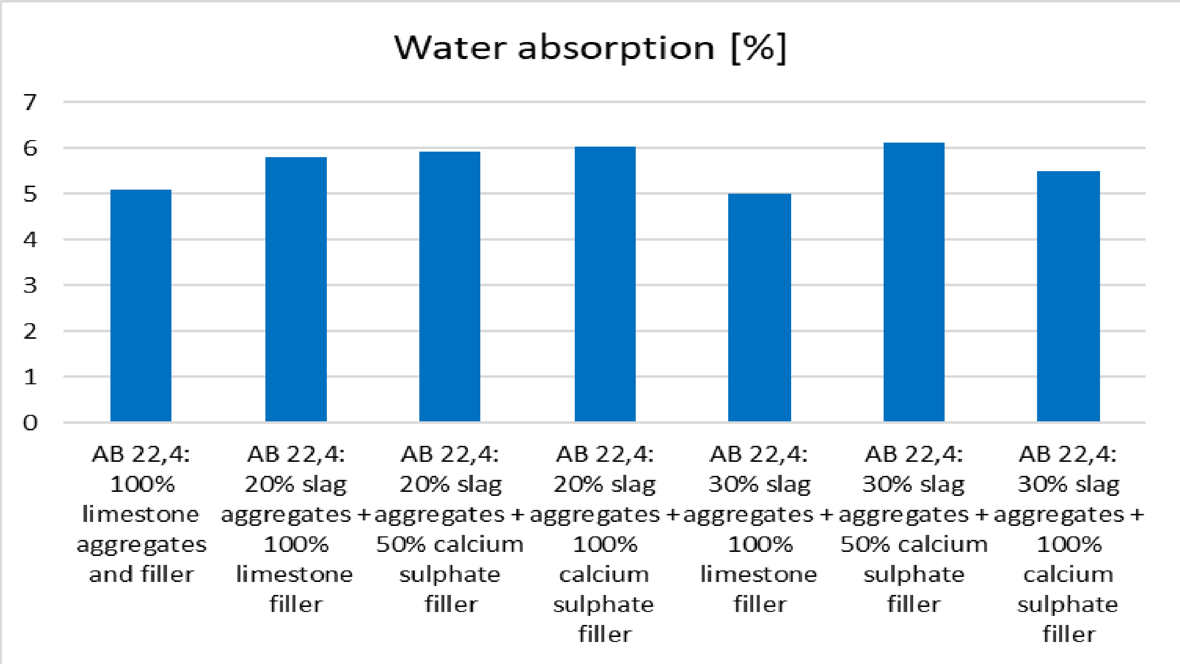

Figure 4. Water absorption depending on industrial wastes in asphalt mixture composition

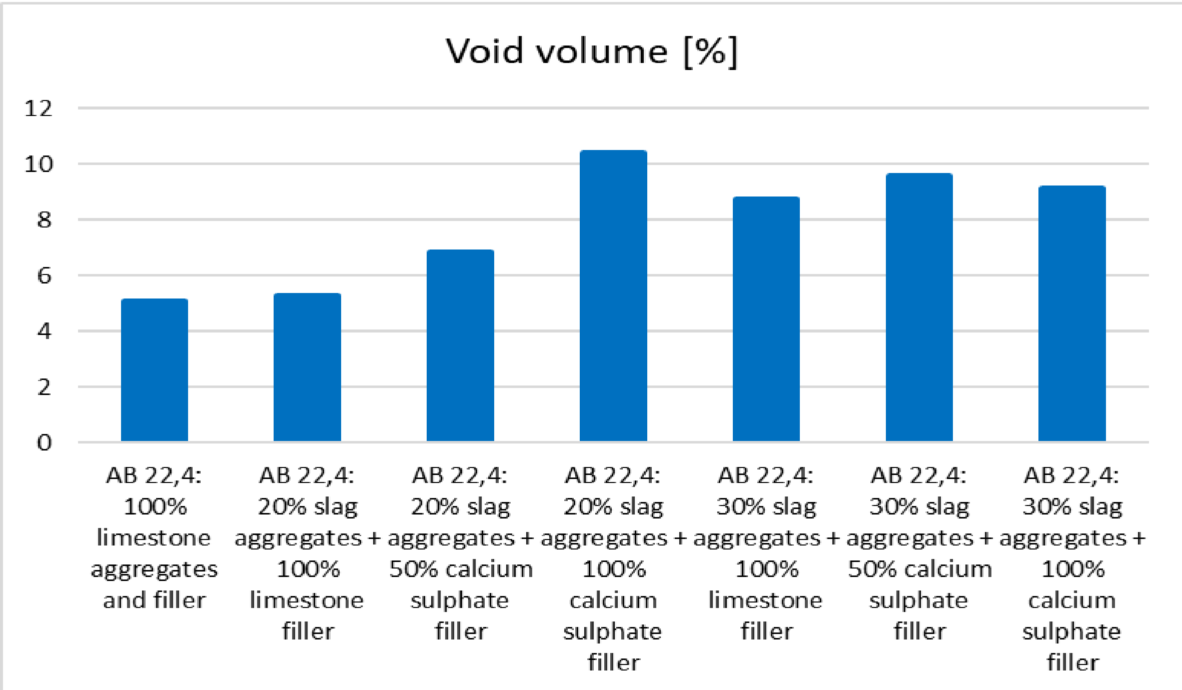

Figure 5. Void volume depending on industrial wastes in the asphaltic mixture composition

It is noted that when using steel slag aggregates and also using steel slag aggregates with calcium sulphate filler both water absorption and void volume increase with using the wastes in asphalt mixture composition.

Therefore, after analyzing all the results of laboratory tests, the research study followed the asphalt mixture recipe which has the best behavior, namely for the utilization of 20% steel slag aggregates and 50% calcium sulphate filler for evaluating also the permanent deformations and fatigue resistance.

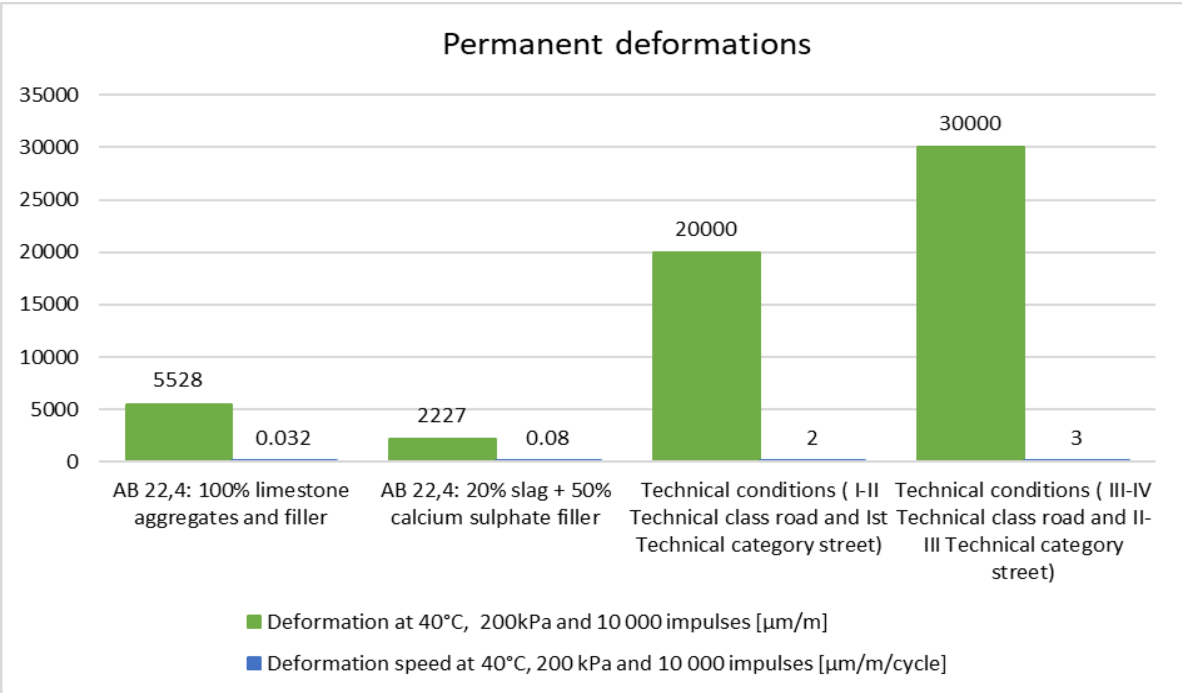

Figure 6. Permanent deformations depending on industrial waste in asphalt mixture composition

Permanent deformation for the asphalt mixture with industrial wastes in composition proves higher deformations speed at a lower deformation compared to standard asphalt mixture. In the same time, both asphalt mixtures prove good behavior compared to the technical conditions according to the AND 605:2016 indicative.

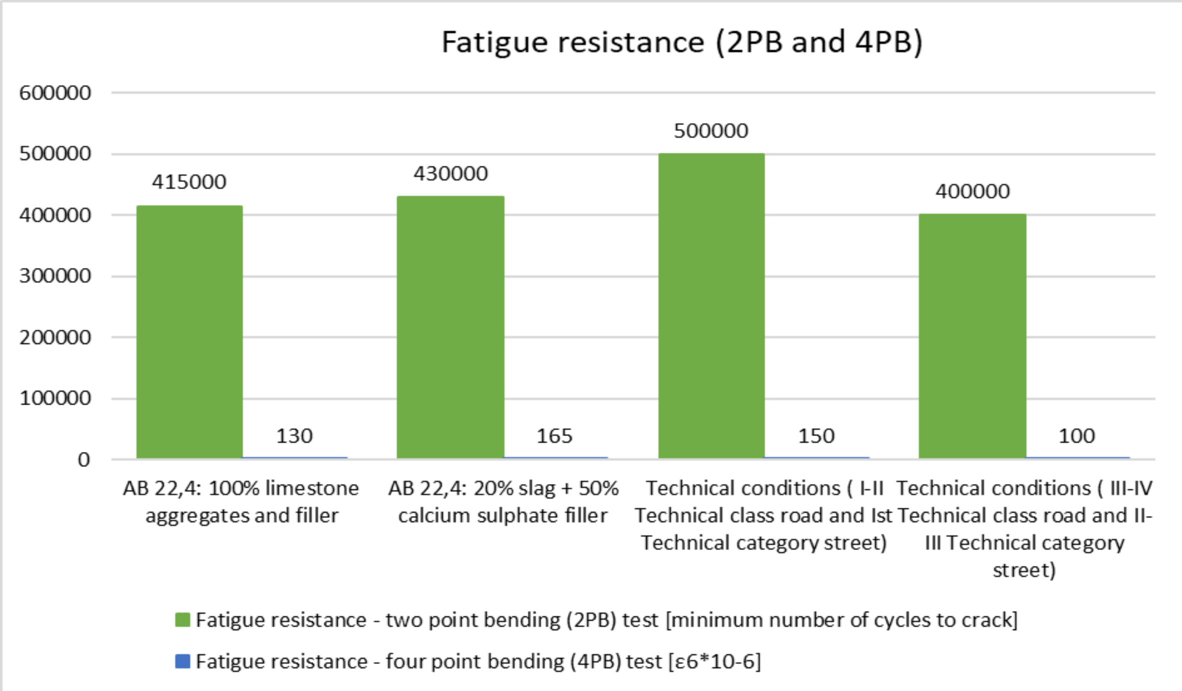

Figure 7. Fatigue resistance depending on industrial waste in asphalt mixture composition

Fatigue resistance proves for both two point and four point bending test that the utilization of industrial wastes in asphalt mixture leads to an improved behavior compared to standard asphalt mixture.

Fatigue cracking due to repeated traffic loadings is a critical distress in asphalt pavements and is also an important consideration in the design of asphalt mixtures and structural design, it is necessary to know that industrial wastes can be used and also that they can improve the behavior of asphaltic mixtures.

5. CONCLUSIONS

This study presents a research on the possibility of using industrial waste in composition of asphalt mixtures such as furnace slags (from thermoelectric power plants) and the calcium sulphate filler (resulting from the desulfurization of the furnace gases).

Based on the results obtained and presented above the following general conclusions can be drawn:

- the D 50/70 road bitumen with industrial waste filler has good behavior, the calcium sulfate filler can normally be used in this type of bitumen, it has been demonstrated that it does not selectively adsorb certain components of the bituminous binder;

- as a result of the evaluations carried out it can be stated that the calcium sulphate filler can be used up to 50% in bituminous mixtures type AB 22,4 with 20% artificial aggregates in composition, it had been proved that for some tests the behavior of asphalt mixture with industrial wastes is improved;
- the analysis of the results demonstrated by asphalt mixtures with 30% artificial aggregates from steel slags leads to the recommendation of using a 100% calcium sulphate filler dosage, this dosage demonstrates better Marshall stability characteristics, water absorption, stiffness modulus and also void volume compared to the use of the combination of 50% limestone filler mixture with 50% calcium sulphate filler;
- the use of these types of industrial waste will result in the protection of natural resources;
- in addition, the use of industrial wastes in the asphalt mixtures leads to reduced environmental pollution due to their elimination.

Nowadays, the transport infrastructure field should reflect more about the concept of recycling and also to responsible consumption and efficiency.

In conclusion, this study underlines the fact that the laboratory tests prove that industrial wastes can be used in asphalt mixture composition, in different dosages, without special needs regarding the temperature or the type of bitumen for the preparation of asphalt mixture recipes.

For the future, it would be interesting to extend the study by taking into account more laboratory testing on various dosages of industrial wastes used in asphalt mixture.

This present study has theoretical nature, from this point of view it would be necessary to carry out an experimental sector with the best solution of asphalt mixture with industrial wastes and to make some laboratory studies to find out the behavior under real exploitation conditions.

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